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The National Vegetation Classification Standard Applied to the Remote Sensing Classification of Two Semiarid Environments

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ABSTRACT / The National Vegetation Classification Standard (NVCS) was implemented at two US National Park Service (NPS) sites in Texas, the Padre Island National Seashore (PINS) and the Lake Meredith National Recreation Area (LMNRA), to provide information for NPS oil and gas management plans. Because NVCS landcover classifications did not exist for these two areas prior to this study, we created landcover classes, through intensive ground and aerial reconnaissance, that characterized the general landscape features and at the same time complied with NVCS guidelines. The created landcover classes were useful for the resource management and were conducive to classification with optical remote sensing systems, such as the Landsat Thematic Mapper (TM). In the LMNRA, topographic elevation data were added to the TM data to reduce confusion between cliff, high plains, and forest classes. Classification accuracies (kappa statistics) of 89.9% (0.89) and 88.2% (0.87) in PINS and LMNRA, respectively, verified that the two NPS landholdings were adequately mapped with TM data. Improved sensor systems with higher spectral and spatial resolutions will ultimately refine the broad classes defined in this classification; however, the landcover classifications created in this study have already provided valuable information for the management of both NPS lands. Habitat information provided by the classifications has aided in the placement of inventory and monitoring plots, has assisted oil and gas operators by providing information on sensitive habitats, and has allowed park managers to better use resources when fighting wildland fires and in protecting visitors and the infrastructure of NPS lands.

The lack of a federal standard for classifying vegetation and the reporting of vegetation statistics has hindered the ability to create timely and consistent synoptic views of all vegetation resources within the United States and worldwide. Natural resource and regulatory agencies document, map, analyze, and report vegetation data in different ways according to their mandates and jurisdictions. This has led to different classification and reporting definitions that are generally divided by broad vegetation and land-use types (e.g., forest, rangelands, wetlands, agricultural lands) or by mission and jurisdiction (e.g., National Forests, Public Lands, National Parks, National Refuges) (VCS 1997). In response to these differences and the need for national synoptic views of vegetation resources, in 1997, the US Federal Geographic Data Committee (FGDC) implemented the National Vegetation Classification Standard (NVCS). The NVCS is based on earlier classification schemes of The Nature Conservancy (TNC 1994), United Nations Educational, Scientific and Cultural Organization (UNESCO 1973), Driscoll and others (1984), and Natural Heritage Programs (URL: http://biology.usgs.gov/npsveg/classification), and it is being considered as a model for a global standard to characterize Earth's land covers (Young 1994, UNEP/FAO 1995,Di Gregoiro and Jansen 1996).

The NVCS provides a basis for consistent national classification and statistics in vegetation resources. Adoption of the standard facilitates the compilation of regional and national summaries, and in turn, provides a detailed, quantitative, and georeferenced data base

KEY WORDS: Accuracy assessment; Color infrared photography; Landsat Thematic Mapper data; National Vegetation Classification Standard; Oil and gas management plans.

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Table 1. Example of National Vegetation Classification Standard (NVCS) hierarchy for typical oak tree wooded area[a]

Division	Vegetated
Order	Tree Dominated
Physiognomic levels (upper 5)	
Physiognimic class	Open tree canopy
Physiognomic subclass	Deciduous
Physiognomic group	Cold deciduous
Physiognomic subgroup	Natural/seminatural
Formation	Upland
Floristic levels (lower 2)	
Alliance	*Quercus garryana*
Association	*Quercus garryana-Quercus kellogii/Rhus diversiloba*

[a]Adapted from VCS, 1997.

for vegetation cover modeling, mapping, and analysis. The standard requires all vegetation classification efforts financed in whole or in part by Federal funds to include NVCS core components [e.g., physiognomic and floristic levels (VCS 1997)]. In cases where the NVCS overlaps with other classification standards, such as the wetlands standard used in wetland and emergent aquatic regions, the standards will be used as complementary (e.g., NVCS primarily classifies vegetation and floristic characteristics whereas the wetlands standard includes soil and other habitat characteristics) in the overall analysis of a geographic area (VCS 1997).

The NVCS is hierarchical: categories are less numerous and more generalized at the higher levels (VCS 1997) (Table 1). The highest level is a division, followed by order, then five physiognomic levels that describe the structure and life form of the plant community, and finally two floristic levels. The division category divides the land into nonvegetated and vegetated levels, and the order category further divides the vegetated division into tree, shrub, dwarf shrub, herbaceous, and nonvascular life forms. Within the physiognomic levels, physiognomic class defines the relative percent canopy cover of each order at the peak of the growing season; physiognomic subclass describes the predominant leaf phenology of woody plants (evergreen, deciduous, mixed evergreen–deciduous) and the leaf type and periodicity of herbaceous plants; physiognomic group relates to a combination of climate, leaf morphology, and leaf phenologic factors; physiognomic subgroup divides the physiognomic group level into natural/semi-natural and planted/cultivated categories; and physiognomic formation divides the physiognomic subgroup into common environmental and additional physiognomic factors [e.g., upland, seasonally flooded, pavement (sparsely vegetated)]. The floristic levels, alliance and association, currently are not required as part of the NVCS (VCS 1997), but they are a required part of all NPS classifications. Alliance represents an aggregation of associations, and association, as the fundamental unit of vegetation in the NVCS, describes a physiognomically uniform group of vegetation stands that share one or more diagnostic (dominant, differential, indicator, or character) overstory and understory species that are generally found in similar habitat conditions (VCS 1997). A complete overview and detailed explanation of the hierarchy (see Table 1) can be found at http://www.fgdc.gov/standards/documents/standards/vegetation/vegclass.pdf

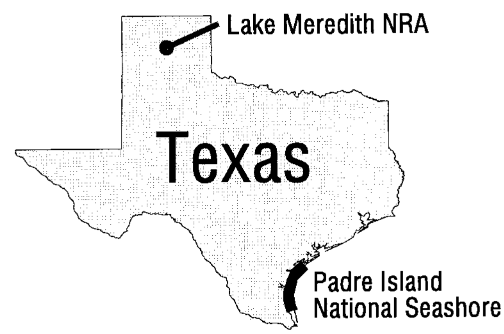

Figure 1. Location of the Lake Meredith National Recreation Area and Padre Island National Seashore in Texas.

Application of NVCS at Two National Park Service Lands

The NVCS was implemented at two US National Park Service (NPS) lands (Figure 1) beginning in 1998 when the NPS began preparing oil and gas management plans (OGMP). The OGMP required that the NPS assess the location, extent, and contents of sensitive habitats within the parks, preserves, and recreation lands. Additionally, the NPS required the mapping to be at a minimum mapping unit of 0.5 ha and georeferenced to USGS 1:24,000 topographic maps. In response to this assessment need, the NPS and US Geological Survey's (USGS) National Wetlands Research Center (NWRC) jointly organized the first NVCS landcover classifications of the Padre Island National Seashore and the Lake Meredith National Recreation Area (Figures 2 and 3).

The Lake Meredith National Recreation Area (LMNRA) exists in the dry and windswept high plains of the Texas Panhandle region known as Llano Estacado. Through this flat surface, the Canadian River has cut 200-ft (61-m) canyons with walls that are crowned with white limestone caprock, buttes, pinnacles, and reddish brown, wind-eroded coves. Above the canyons lie the mesquite, prickly pear, yucca, and mixed grasses common to the southern arid high plains. Cottonwoods, soapberry, and sandbar willows are found around the lake and river shore.

The Padre Island National Seashore (PINS) stretches out in the microtidal region of the southwest Gulf of Mexico. The steady wave and wind sculpting of the long and narrow barrier island occasionally give way to cataclysmic storm erosion of the barrier island and deposition in the normally hypersaline, shallow, back-barrier lagoon—the Laguna Madre. Landward of the beach, bluestem and sea oats occupy the sparsely vegetated sand dunes; bulrush, cattails, and black willow dominate the emergent marshes, and a mixture of upland and wetland plants such as bluestem and cordgrass make up a majority of the densely vegetated grasslands. On the Laguna side of the island, sparsely vegetated unconsolidated shores and washover channels transform into expansive fine sand and mud wind tidal flats that are often covered with blue-green algae.

Prior to this study, no NVCS landcover classification existed for either the LMNRA or the PINS and no regional classification using national standards (such as NVCS) existed for the semiarid plains and the barrier island systems of the Southwest. Thus, the original objective to provide vegetation classifications of the PINS and LMNRA adhering to NVCS was expanded to include a definition for each landcover class (Tables 2 and 3). In our classification, the definition of landcover classes had to follow four main criteria. First, the classes needed to adequately describe and quantify the land covers within the context of the regional landscape, and the classes needed to be scalable. Scalability applies to classes containing landcover mixtures within a defined minimum mapping unit (MMU). As the MMU decreases and the class mixtures are further separated, new landcover classes can be defined totally subordinate (e.g., mutually exclusive at each hierarchical level) to the original mixed landcover class. Second, the prescribed landcover classes are appropriate for operational mapping and monitoring systems. If the system is unable to identify the defined land covers and detect changes in those land covers, the class definitions (e.g., aggregation) or system must change. This point also is germane to the issues of MMU and scalability. Landsat Thematic Mapper (TM) was the primary mapping system used, and it provided a MMU of about 0.1 ha, a higher resolution than the 0.5 ha the NPS mandated. As mapping systems are improved and class definitions are refined, continuity to the past landcover classifications could be preserved. Third, the landcover classes had to be applicable to the regulatory policies and resource management of the area. This was assured by involvement of NPS personnel in the creation of the landcover classes. Fourth, the landcover classes had to follow the NVCS hierarchy.

In this paper, we demonstrate our application of NVCS to defining landcover classes and, subsequently, to mapping those classes at the PINS and LMNRA. Landcover classes defined here could be useful in other classifications of the high plains and barrier island systems of the Southwest, and generally, as a template when no other classification standards exist. Field techniques used to identify and define landcover classes following the NVCS, the landcover definitions provided here, and the remote sensing techniques used to map and validate the mapped distributions should serve as a guideline for future landcover mapping of these and similar areas.

Methods

At both the PINS and LMNRA, the landcover classification began with ground-based field surveys by USGS and NPS personnel. Expert knowledge from NPS personnel and site reconnaissance were used to build a general account of the pervasive vegetation assemblages, dominant vegetation types (life forms), and their general percentage within these assemblages, physiognomic attributes of the dominant vegetation, and the general geology and hydrology associated with each assemblage. Field notes taken at each site also documented the location, species percent composition (over about 5%, unless an indicator species), vegetation groundcover, and the approximate height of all dominant vegetation. Pictures were also taken and recorded at all ground sites. At both the PINS and LMNRA, helicopter surveys were used to aid ground-based reconnaissance. At the end of field surveys, the vegetation at PINS and LMNRA was designated to a physiognomic level (class, subclass, group, subgroup, formation) and a floristic level (alliance, association) (Tables 4 and 5).

Following the initial field surveys and site assignments, Landsat Thematic Mapper (TM) data covering

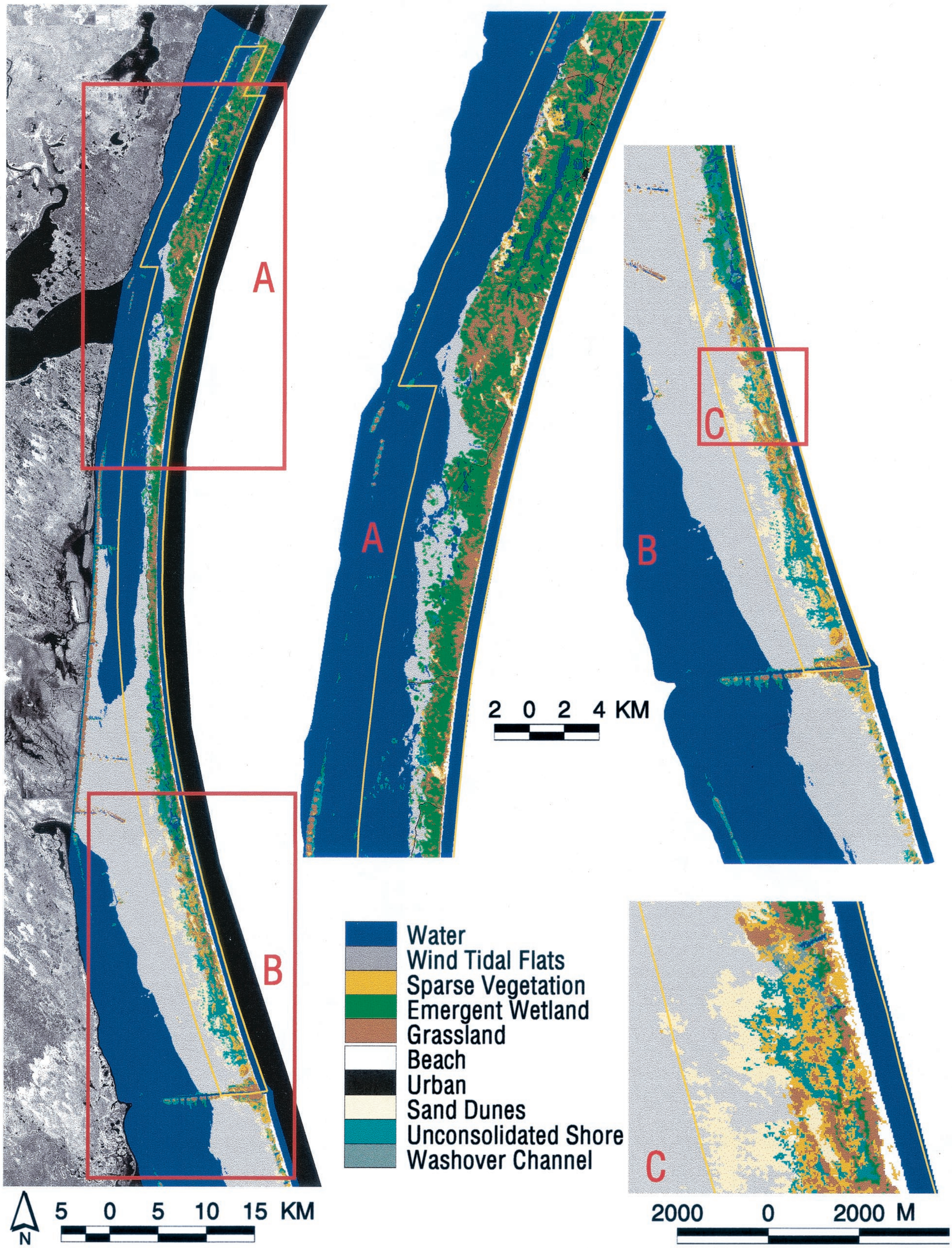

Figure 2. Classification map of the Padre Island National Seashore (PINS). The yellow line encloses the National Park Service land at PINS (boundary provided by Park Service personnel). Inserts A and B illustrate areas with detailed view of the vegetation distribution. Insert C shows full resolution vegetation coverage of an area from insert B.

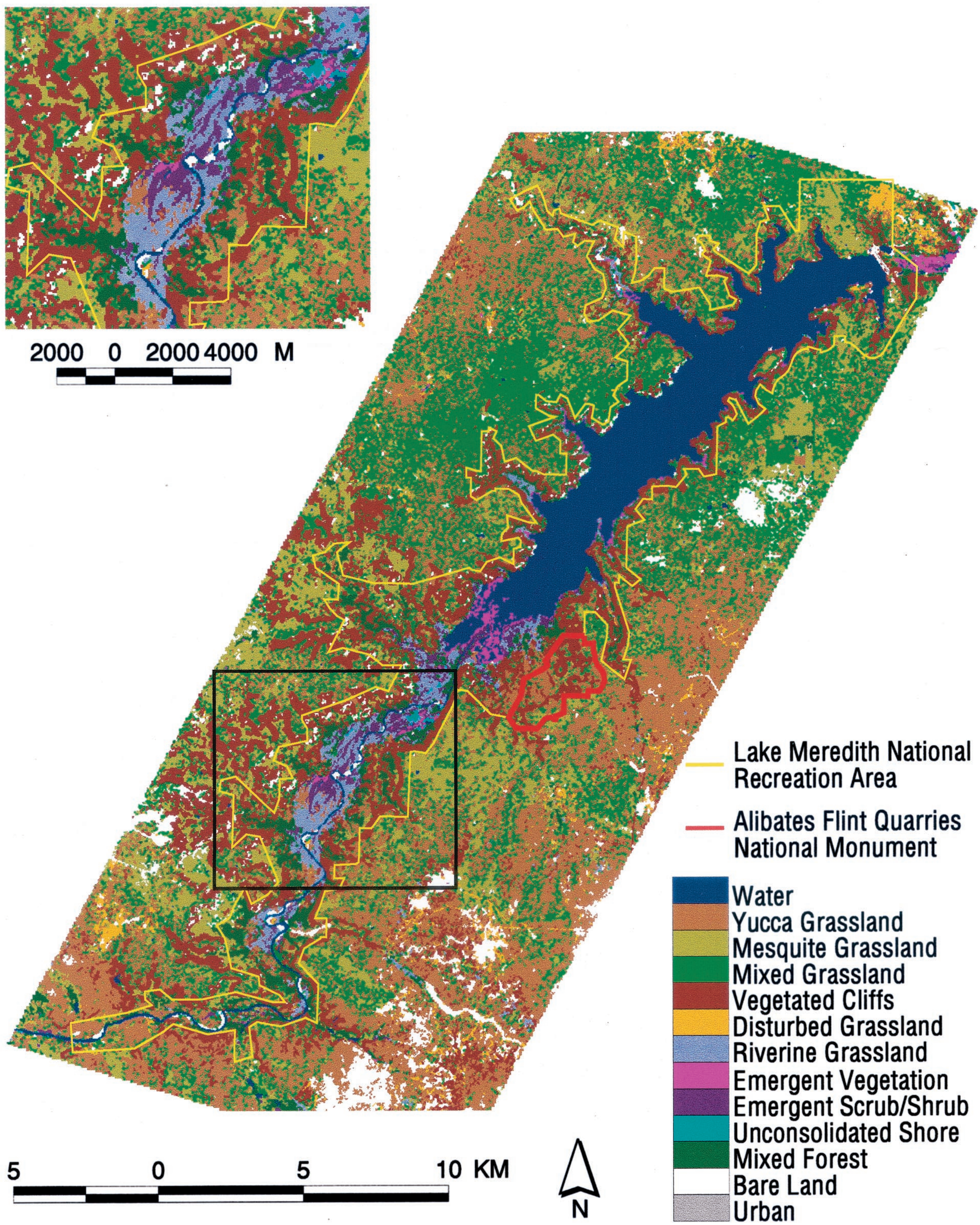

Figure 3. Classification map of the Lake Meredith National Recreation Area (LMNRA) and Alibates Flint Quarries National Monument (boundary provided by Park Service personnel). The square box defines an area that is enlarged at the top left with detailed view of the vegetation distribution. Note that the classification map also covers a large area outside the LMNRA.

Table 2. General class descriptions and National Vegetation Classification Standards designations for the Padre Island National Seashore

Inland Water	Semipermanent areas of standing fresh water that are found parallel to the foredune ridge along the interior of the island. Depending on depth, vegetation may consist of species such as pennywort (*Hydrocotyle bonariensis*).
Laguna Madre	A hypersaline lagoon occurring between the Texas mainland and the barrier island. Several species of seagrasses occur in this habitat including shoal grass (*Halodule wrightii*), manatee grass (*Cymodocea filiformis*), and widgeon grass (*Ruppia maritima*).
Gulf of Mexico	Gulf of Mexico bordering the eastern edge of the barrier island.
Wind Tidal Flat	Expanses of fine sand and mud along the western edge of the barrier island. It is periodically inundated with saltwater pushed ashore by northern winds. It is often vegetated with the blue-green algae (*Lyngbya confervoides*).
Sparse Vegetation	Sand dunes of varying height that are sparsely vegetated with seacoast bluestem (*Schizachyrium littorale*), sea oats (*Uniola paniculata*), bitter panicum (*Panicum amarum*), and other grasses and forbs.
Emergent Wetland	Shallow depressions that are inundated with fresh water from rain events or saltwater from tropical storms. These areas are vegetated with bulrush (*Scirpus americanus*), cattails (*Typha domingensis*), black willow (*Salix nigra*), gulfdune paspalum (*Paspalum monostachyum*), and pennywort (*Hydrocotyle bonariensis*).
Grassland	Areas containing dune hummocks that are densely vegetated with grasses including seacoast bluestem (*Schizachyrium littorale*), cordgrass species (*Spartina sp.*), gulfdune paspalum (*Paspalum monostachyum*), bushy bluestem (*Andropogon glomeratus*), and others.
Beach	A thin area extending the entire length of the island adjacent to the Gulf of Mexico. It varies in width depending on the season and is made up of sand and shell fragments with no vegetation.
Urban	Developed areas including roadways, buildings, and visitor services.
Sand Dunes	Areas of nonvegetated sand located immediately landward of the beach or along the western edge of the barrier island.
Unconsolidated Shore	Areas adjacent to washover channels and inland water areas consisting of fine sands with little to no vegetation. If vegetation is present, it is sparse with species such as cattails (*Typha domingensis*) or bulrush (*Schoenoplectus americanus*).
Washover Channel	Channels created by tropical storms that are cut perpendicular to the beach through the foredune ridge. These areas may contain water from rain events. If water is present, vegetation may consist of blue green algae such as *Lyngbya confervoides*.

the PINS and LMNRA were rectified to a UTM projection and coordinate system. A root-mean-square error of less than ±12.5 m positional accuracy was obtained for each of the TM image. A progressive clustering technique was then used to classify the georeferenced TM images (Ramsey and Laine 1997, Ramsey and others 1998). In the classifications, the six reflective spectral band values each associated with 25 m × 25 m TM data element (pixel) were combined into spectrally similar clusters. These clusters were then associated with identifiable earth features. Identified features were the land covers described by physiognomic and floristic levels documented during the site reconnaissance (Tables 4 and 5). The georeferenced TM spectral data were then transformed into landcover information as defined by the NVCS.

Classified maps were taken to the respective NPS lands where USGS and NPS personnel conducted field verification and evaluated the performance of the initial classifications. Evaluation included field checks of classified areas outside of field sites used in creation of the landcover classes. Evaluation suggested the PINS classification accuracy was satisfactory. Initial classification of the LMNRA, however, was not acceptable because of high classification confusion among vegetation classes found on cliffs and high plains. Classification confusion was also prevalent between the floristic associations proposed for the various types of evergreen forests. Aggregation of all cliff vegetation into a single class (vegetated cliffs), and all forest floristic associations into a single floristic association alleviated most classification confusion. Confusion still existed, however, between the vegetated cliff and high plains landcover classes. In order to resolve this problem, topographic data were introduced to the classification of the LMNRA.

Six digital topographic files, each representing one 7.5-min US Geological Survey (USGS) quadrangle, were acquired. Topographic mapping was at 10-m contour intervals, and topographic accuracy was ±5 m with a maximum expected root-mean-square error of propagation of ±5.85 m (Eric Constance, personal communication, USGS-National Mapping Division). The digital files were georeferenced, mosaicked, and registered to the TM image data base. Absolute elevation was not used directly to separate the cliff from the high plains classes. Instead, the absolute elevations were transformed to the rate of change of elevation (slope) at each pixel. This slope transform ensured that the method would be applicable to a wider range of similar classification problems. As expected, the highest slopes were associated with the cliffs and the lowest with the

Table 3. General class descriptions and National Vegetation Classification Standards designations for the Lake Meredith National Recreation Area

Water—Open lake and river water.
Yucca Grassland—Areas that are densely vegetated with small soapweed yucca, mesquite, blue stem grass, grama grasses, purple threeawn grass, and others, with predominant larger vegetation of yucca.
Mesquite Grassland—Areas that are densely vegetated with mesquite, small soapweed yucca, blue stem grasses, grama grasses, purple threeawn, and others, with predominant larger vegetation of mesquite.
Mixed Grassland—Areas that are densely vegetated with mesquite, small soapweed yucca, blue stem grasses, purple threeawn, and others. Mixed large vegetation may be mesquite, yucca, or other woody plants.
Vegetated Cliffs—Sloped edges along ravines that are sparsely vegetated with bluestem, mesquite, grama grasses, net-leaf hackberry, soapberry, and others.
Disturbed Grassland—Areas that are sparsely vegetated often on more rocky or sandy soil with bluestem grasses, grama grasses, ragweed, and others.
Riverine Grassland—Areas that are densely vegetated with switchgrass, common reed, seep willow, salt cedar, yellow or white sweet clover, and others.
Emergent Vegetation—Low-lying areas that may be inundated with fresh water from rain events or lake level fluctuations. These areas are vegetated with reeds, rushes, cattails, bulrush, and others.
Emergent Scrub Shrub—Low-lying areas that may be inundated with freshwater from rain events or lake level fluctuations. These areas are vegetated with reeds, switchgrass, and larger vegetation types such as cottonwoods, willows, salt cedar, and seep willow.
Unconsolidated Shore—Areas adjacent to inland water areas consisting of fine sands with little to no vegetation. If vegetation is present, it is sparse with species such as saltgrass, salt cedar, or herbaceous plants.
Mixed Forest—Areas that are densely populated with trees. Species can include hackberry, one-seed juniper, cottonwood, soapberry, mesquite, and salt cedar.
Bare Land—Areas that have sparse to no vegetation.
Urban—Areas with human-made structures including dams, buildings, paved roadways, concrete piers, and oil field platforms.

nearly flat high plains. The slope information was then added into the classification as another data layer along with the six TM reflective bands. With this addition, the cliff landcover classes were successfully separated from high plain landcover classes. A three-by-three mode filter was used on the final classified map to reduce classification error and noise (Jensen and others 1994). The final classification of the LMNRA was then subjected to accuracy assessment.

Accuracy assessments of both PINS and LMNRA classifications used a class-stratified random-sample design. Except for the urban class in the PINS, all other landcover classes included more than 30 verification points (van Genderen and Lock 1977) to assess the accuracy of our classified imagery (Table 6). The 644 assessment points from the 12 landcover classes of the PINS area included points identified from a high-resolution CIR photography (1:32,500) taken in 1994 and field verification from a helicopter platform conducted in April 1998. In the LMNRA, 30 points for each of the 13 landcover classes totaling 390 points (Table 7) were located in CIR photography (1:65,000) collected in January and February of 1996 and 1997 that was acquired from the USGS National Aerial Photography Program (NAPP). Assessment points located on the CIR photography and during the helicopter surveys were then assigned to a landcover class. Accuracy assessment was performed by comparing the classification results to the results of the CIR photography interpretation and the helicopter and ground-based field surveys within a contingency matrix (Tables 6 and 7).

Results

General class descriptions of PINS and LMNRA land covers (Tables 2 and 3) are listed with NVCS descriptions (Tables 4 and 5). General descriptions were created from site observations collected in the initial field surveys. The landcover description of the PINS was fairly straightforward. Among the 12 landcover classes (Table 2), three land covers were related to water regimes, one to developed urban, and the remaining eight land covers to geologic and geomorphic features (e.g., sand dune, beach). Except for open water and developed urban classes, land covers in and surrounding the LMNRA were divided generally into those found in close proximity to the open water, those found on the cliffs, and those found on the high plains.

A 0.89 kappa statistic [scaled measure of accuracy that incorporates omission and commission error (Congalton 1991)] and an overall accuracy (ratio of the total correct to total assessment points) determined that at least 89% of the PINS classification was correct (Table 6). In addition to statistics describing the overall

Table 4. Classified landcovers with National Vegetation Classification Standard (NVCS) applied to Padre Island National Seashore

	Landcover classes mapped with Landsat TM image data					
	Inland water	Laguna Madre	Gulf of Mexico	Wind-tidal flats	Sparse vegetation	Emergent vegetation
NVCS						
Division	Vegetated	Vegetated	Not vegetated	Vegetated	Vegetated	Vegetated
Order	Herbaceous dominated	Herbaceous dominated		Vegetation not dominant	Vegetation not dominant	Herbaceous dominated
NVCS Physiognomic Levels						
Class	Herbaceous vegetation	Herbaceous vegetation		Sparse vegetation	Sparse vegetation	Herbaceous vegetation
Subclass	Parennial graminoid	Hydromorphic rooted veg.		Unconsolidated material sand/mud	Unconsolidated material sand/mud	Parennial graminoid
Group	Tropical or subtropical	Tropical or subtropical		Sparsely veg. soil flats	Sparsely veg. sand dunes	Tropical or subtropical
Subgroup	Natural/seminatural	Natural/seminatural		Natural/seminatural	Natural/seminatural	Natural/seminatural
Formation	Semipermanently flooded	Permanently flooded		Tidal mud flats	Sparse herbaceous veg.	Seasonally flooded
NVCS Floristic Levels						
Alliance	*Hydrocotyle bonariensis*	*Halodule wrightii*		*Lyngbya confervoides*	*Schizachyrium littorale*	*Typha domingensis* (north end). *Scirpus americanus* (south end).
Association	*Hydrocotyle bonariensis*	*Halodule wrightii/ Cymodocea filiformis*		*Lyngbya confervoides*	Seacoast bluestearn, *Schizachyrium littorale*	Cattail, *Typha domingensis* (north end) American bulrush, *Scirpus americanus* (south end).

Table 5. Classified landcovers with National Vegetation Classification Standard (NVCS) applied to Lake Meredith National Recreation Area

	Landcover classes mapped with Landsat TM image data					
	Water	Yucca grassland	Mesquite grassland	Mixed grassland	Vegetated cliffs	Disturbed grassland
NVCS						
Division	Not Vegetated	Vegetated	Vegetated	Vegetated	Vegetated	Vegetated
Order		Herbaceous dominated	Herbaceous dominated	Herbaceous dominated	Herbaceous dominated	Herbaceous dominated
NVCS Physiognomic Levels						
Class		Herbaceous vegetation	Herbaceous vegetation	Herbaceous vegetation	Herbaceous vegetation	Herbaceous vegetation
Subclass		Perennial graminoid	Perennial graminoid/woody	Perennial graminoid/woody	Perennial graminoid/woody	Perennial graminoid/woody
Group		Temperate grassland	Temperate grassland	Temperate grassland	Temperate grassland	Temperate grassland
Subgroup		Natural/seminatural	Natural/seminatural	Natural/seminatural	Natural/seminatural	Natural/seminatural
Formation		Medium-tall grassland/ deciduous shrub layer	Medium-tall grassland/sparse mix tree layer	Medium-tall grassland/sparse mix tree layer	Medium-tall grassland/ deciduous shrub layer	Short bunch temperate grassland
NVCS Floristic Levels						
Alliance		Yucca–*Bouteloua*	*Prosopis–Bouteloua*	Yucca, *Prosopis, Bouteloua*	*Rhus trilobata*	Ambrosia/Salsola/ *Bouteloua*
Association		Yucca–grama grass	Mesquite grassland	Yucca/mesquite grassland	Skunkbush (*Rhus trilobata*)	Russian thistle, ragweed, *Bouteloua*

classification accuracy, error measures were calculated detailing omission and commission error associated with each landcover class. Omission error percentages revealed the number of reference points (i.e., photography, helicopter, and field) omitted and incorrectly classified relative to the total number of reference points per class (Table 6). The highest omission error was associated with sparse vegetation. This class was

Table 4 (Continued)

Landcover classes mapped with Landsat TM image data					
Grassland	Beach	Urban	Sand dunes	Unconsolidated shore	Washover channel
Vegetated	Not vegetated	Not vegetated	Not vegetated	Vegetated	Vegetated
Herbaceous dominated				Vegetation not dominant	Vegetation not dominant
Herbaceous vegetation				Sparse vegetation	Sparse vegetation
Parennial graminoid				Unconsolidated material sand/ mud	Unconsolidated material sand/ mud
Tropical or subtropical				Sparsely veg. soil flats	Sparsely veg. soil flats
Natural/seminatural				Natural/seminatural	Natural/seminatural
Medium–tall bunch				Seasonally flooded mud flats	Intermittently flooded mud flats
Schizachyrium littorale (north end). *Paspalum monostachyum* (south end).				Blue green algae sp.	*Lyngbya confervoides*
Seacoast bluestearn, *Schizachyrium littorale* (north end). Seacoast bluestearn, *Schizachyrium littorale*, Gulf-dune paspalum *Paspalum monostachyum* (south end).				Blue green algae sp.	*Lyngbya* confervoides

Table 5 (Continued)

Landcover classes mapped with Landsat TM image data						
Riverine grassland	Emergent vegetation	Emergent scrub, shrub	Unconsolidated shore	Mixed forest	Bare land	Urban
Vegetated	Vegetated	Vegetated	Vegetated	Vegetated	Not Vegetated	Not Vegetated
Herbaceous dominated	Herbaceous dominated	Arboreal	Veg. not dominant	Tree dominated		
Herbaceous vegetation	Herbaceous vegetation	Arboreal	Sparse vegetation	Open tree canopy		
Perennial graminoid/woody	Perennial graminoid	Perennial woody	Unconsolidated material sand/ mud	Deciduous		
Temperate grassland	Temperate grassland	Temperate	Sparsely veg. soil flats	Tropical deciduous		
Natural/seminatural	Natural/seminatural	Natural/seminatural	Natural/seminatural	Natural/seminatural		
Seasonally flooded grassland	Seasonally flooded herbaceous	Seasonally flooded scrub zone	Seasonally flooded	Lowland or submontane broad leaved		
Phragmites, *Baccharis*	*Scirpus americanus*	*Rhus trilobata*	*Cyanobacteria* sp.	Various arboreal		
Phragmites, *Baccharis*	American bulrush, (*Scirpus americanus*)	Skunkbush (*Rhus trilobata*)	*Cyanobacteria* sp.	Various woody		

confused with a wide number of other classes. The next highest omission errors were associated with unconsolidated shore. Most errors were related to misclassification of unconsolidated shore into physically and spectrally similar classes and water classes. Commission error percentages revealed the number of misclassified pixels incorrectly included in a landcover class relative to the total number of classification points per class

Table 6. Accuracy assessment of PINS classified image compared to CIR photography and field verification

Classified TM image	Landcover observed from CIR photography and field verification													
	IW	LM	GoM	WTF	SV	EV	G	B	U	SD	US	WC	Total	Commission %
1. Inland water	43	0	0	0	0	1	0	0	0	0	1	0	45	4
2. Laguna Madre	0	52	0	0	0	0	0	0	0	0	2	0	54	4
3. Gulf of Mexico	0	0	58	0	0	0	0	4	0	0	1	0	63	8
4. Wind tidal flats	0	0	0	60	3	2	0	0	0	5	3	0	73	18
5. Sparse vegetation	0	0	0	0	45	0	0	1	0	0	3	2	51	12
6. Emergent vegetation	2	0	0	0	2	81	5	0	1	0	1	0	92	12
7. Grassland	0	0	0	0	3	8	50	0	0	0	0	0	61	18
8. Beach	0	0	0	0	2	0	0	46	0	0	0	0	48	4
9. Urban	0	0	0	0	0	0	0	0	21	0	0	0	21	0
10. Sand dunes	0	0	0	0	0	0	0	0	0	46	0	0	46	0
11. Unconsolidated shore	0	1	0	1	5	0	1	0	0	0	41	0	49	16
12. Washover channel	0	0	0	0	1	2	0	0	0	0	2	36	41	12
Total	45	53	58	61	61	94	56	51	22	51	54	38	644	
Omission (%)	4	2	0	2	26	14	11	10	5	10	24	5	Overall accuracy: 89.91%	
Correctly classified (%)	96	98	100	98	74	86	89	90	95	90	76	95	Kappa statistic: 0.89	

Table 7. Accuracy assessment of LMNRA classified image compared to CIR photography

Classified TM image	Landcover observed from CIR photography														
	W	YG	MeG	MiG	VC	DG	RG	EV	ESS	US	MF	BL	U	Total	Commission %
1. Water	30	0	0	0	0	0	0	0	0	0	0	0	0	30	0
2. Yucca grassland	0	24	0	10	0	0	0	0	0	0	0	0	0	34	29
3. Mesquite grassland	0	0	28	0	0	0	0	0	0	0	5	0	0	33	15
4. Mixed grassland	0	6	1	20	0	0	0	0	0	0	0	0	0	27	26
5. Vegetated cliff	0	0	0	0	30	0	0	0	0	0	0	0	0	30	0
6. Disturbed grassland	0	0	0	0	0	22	0	0	0	0	0	4	0	26	15
7. Riverine grassland	0	0	0	0	0	0	26	0	0	0	0	0	0	26	0
8. Emergent vegetation	0	0	0	0	0	0	2	29	0	0	0	0	0	31	6
9. Emergent scrub shrub	0	0	0	0	0	0	2	0	30	0	1	0	0	33	9
10. Unconsolidated shore	0	0	0	0	0	0	0	1	0	27	0	0	0	28	4
11. Mixed forest	0	0	1	0	0	0	0	0	0	0	24	0	0	25	4
12. Bare land	0	0	0	0	0	6	0	0	0	3	0	24	0	33	27
13. Urban	0	0	0	0	0	2	0	0	0	0	0	2	30	34	12
Total	30	30	30	30	30	30	30	30	30	30	30	30	30	390	
Omission (%)	0	20	7	33	0	27	13	3	0	10	20	20	0	Overall accuracy: 88.21%	
Correctly classified (%)	100	80	93	67	100	73	87	97	100	90	80	80	100	Kappa statistic: 0.87	

(Table 6). Wind tidal flats and grasslands were associated with the highest commission errors. Misclassification of sparse vegetation, sand dunes, and unconsolidated shore was responsible for most of the commission error associated with wind tidal flats. Most commission error related to grassland was due to confusion with sparse and emergent vegetation. Unconsolidated shore was also associated with relatively high commission errors (Table 6).

Accuracy assessment of the LMNRA landcover classification determined an overall 88% classification accuracy with a 0.87 kappa statistic (Table 7). Yucca, mixed, and disturbed grasslands, mixed forest; and bare land were the most likely classes to be incorrectly classified as another land cover (omission error). On the other hand, yucca and mixed grasslands and bare land were also the most likely classes to gain coverage from the misclassification of other land covers (commission error). Mesquite and disturbed grassland also were associated with relatively high commission errors (Table 7).

Excluding the Gulf of Mexico and Laguna Madre waters, wind tidal flats, grasslands, and emergent vegetation cover constituted around 70% of the PINS land area (Table 8). Sparse vegetation, sand dunes, beach and unconsolidated shore make up most of the remain-

Table 8. Landcovers association[a]

Padre Island National Seashore (PINS)			Lake Meredith National Recreation Area (LMNRA)		
Class	Hectare	% PINS area	Class	Hectare	% LMNRA area
1. Inland water	946.77	1.82	1. Water	4,332.06	25.38
2. Laguna Madre	12,143.69	23.38	2. Yucca grassland	1,800.77	10.55
3. Gulf of Mexico	5,113.02	9.84	3. Mesquite grassland	1,159.51	6.79
4. Wind tidal flats	11,298.18	21.75	4. Mixed grassland	2,165.42	12.68
5. Sparse vegetation	2,444.09	4.70	5. Vegetated cliff	3,563.83	20.88
6. Emergent vegetation	7,683.92	14.79	6. Disturbed grassland	192.54	1.13
7. Grassland	5,356.37	10.31	7. Riverine grassland	844.68	4.95
8. Beach	1,291.74	2.49	8. Emergent vegetation	313.92	1.84
9. Urban	170.15	0.33	9. Emergent scrub shrub	563.39	3.30
10. Sand dunes	2,422.42	4.66	10. Unconsolidated shore	81.02	0.47
11. Unconsolidated shore	2,613.16	5.03	11. Mixed forest	1,658.05	9.71
12. Washover channels	463.41	0.89	12. Bare land	390.37	2.29
			13. Urban	5.29	0.03
Total	51,946.92	100.00	Total	17,070.85	100.00

[a]Boundaries of PINS and LMNRA were provided by the respective Park Service personnel.

ing PINS land cover. Water covers about 25% of the LMNRA and vegetated cliffs, yucca and mixed grasslands and mixed forest make up nearly 54% of the land area (Table 8). Mesquite and riverine grasslands, emergent scrub shrub and bare land constitute most of the remaining land cover of the LMNRA.

Discussion

Overall, land covers devised for the classification of the PINS and the LMNRA were adequately mapped with respect to the objectives of our study. Certain land covers, however, were associated with misclassification errors that should decrease with the use of improved sensor systems. Sparse vegetation, unconsolidated shore, and wind tidal flats within the PINS classification were particularly beset with misclassifications. Higher spatial resolution data should lessen the confusion between wind tidal flats and sparse vegetation. Subtle spectral variation between wind tidal flats and sand dunes and unconsolidated shore, however, may necessitate the use of remote sensing systems with higher spectral sensitivity to decrease classification confusion among these classes. Higher spectral resolution and possibly multitemporal data may be required to improve separation between emergent vegetation and grassland. Improvement in the classification of unconsolidated shore will also come about with higher spatial resolution and/or multitemporal data, but differences in water levels between the time of data collection and assessment observation will continue to hinder proper accuracy assessment of this and other transition classes.

In the LMNRA classification, sensors with improved spectral resolution will more likely help to correct classification confusion than those with higher spatial resolution. Indicator species, such as yucca and mesquite, rarely constitute more than a fraction of the pixel. Most often, various grasses cover the ground providing a brown spectral background for the more green herbaceous plants. In this fairly constant brown background, the highest contributor to the spectral variability is the variation in density of the yucca, mesquite, and trees intermixed in the grassland matrix. Changes in density, however, were not necessarily used as an indicator of grassland type. Class type discrimination relied on the more subtle spectral differences between the indicator species (e.g., yucca, mesquite).

Increased spectral resolution will also lessen the confusion between disturbed grasslands and bare land areas. It could also provide the ability to further separate the forest class into forests dominated by different tree species, such as cedar and willow, and possibly provide the ability to detect stands of the gregarious invasive species, such as salt cedar. Higher spectral resolution data may afford higher detailed mapping of the emergent classes, such as cane, and again, salt cedar. With finer spectral and spatial resolutions, the invasive species, silvergrass, may be spectrally separable from other riverine grasses. Finally, higher spectral and spatial resolution data should provide increased discrimination of cliff assemblages, but variable shadowing and ubiquitous gypsum outcrops will continue to thwart more detailed mapping of these areas. In total, the classification accuracy assessments verified that the Landsat TM data provide a basis for deciphering differences between PINS and LMNRA landcovers, but increased discrimination capability will require increased spatial and spectral resolutions and possibly multitemporal data.

Conclusions

Landcover classifications for two National Parks Service lands were developed to provide valuable information about sensitive habitats for NPS oil and gas management plans. The NVCS applied to the landcover classifications provides a basis for a continued consistent vegetation classification. The classification accuracy percentages of 89.9% in PINS and 88.2% in LMNRA verified that the classified land covers of the two NPS lands were adequately mapped with TM data, fulfilling the objectives of our study. In the LMNRA, aggregation of classes and the use of topographic elevation data resolved most confusion between cliff, high plains, and forest classes, but classification confusion remained among spectrally unseparable classes. Improved sensor systems with higher spectral and spatial resolutions, however, should remove most of the remaining confusions. Landcover refinement will also occur with the use of an improved sensor system and multitemporal collections. In the PINS, for example, the grasslands and emergent vegetation classes are comprised of a number of assemblages separable at the floristic level that are not separable with the current TM data. Similarly, the LMNRA classification includes broadly defined landcover classes. As sensor systems improve and provide higher spectral and spatial resolution data, the broad classes defined in this classification can be further subdivided. The increased spatial, and especially spectral, resolutions should aid in the detection and mapping of invasive species present in the LMNRA. The detailed landcover information will progress as the collection systems advance.

Even though more detailed classification will result from improved sensor systems with higher spectral and spatial resolution data, the landcover classifications created in this study have provided NPS personnel valuable information for the management of both the PINS and the LMNRA (park service personnel, personal communication). The classified vegetation maps provided habitat information to guide the placement of inventory and monitoring plots for examining fire effects to seashore habitats and for gathering baseline information on reptiles, birds, vegetation, etc. Furthermore, potential fire movements based on assessment of vegetation maps has allowed park management to better utilize resources when fighting wildland fires and protecting visitors and the infrastructure of NPS lands. Habitat information from the vegetation maps has assisted oil and gas operators by providing them information on sensitive habitats. This information is then used to determine their cost and their impacts to the resources. Information from the vegetation map has aided park management in their planning efforts by providing a base map upon which to overlay other data layers and create maps that are used during public scoping sessions. The vegetation map has become the single most important data layer for the analysis of natural threats, impacts, resources, and development options to the NPS landholdings.

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